Development of a Space-Flight ADR Providing Continuous Cooling at 50 mK With Heat Rejection at 10 K

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Introduction

- Future (post-PIXIE) flight missions will need:
  - sub-Kelvin cooling with higher heat loads than past missions
  - significant cooling at 2 – 6 K optics/instrument temperature

- NASA/GSFC is developing a flight-ready 10 to 0.05 K continuous ADR (CADR) to meet these needs

Performance Requirements

- Anticipated future missions with sub-Kelvin detector arrays:
  - Origins Space Telescope
  - Lynx
  - Inflation Probe
  - Possibly HabEx and LUVOIR
- Proposed CADR can exceed expected performance requirements

Performance metrics	Requirements	Current SOA	Proposed CADR
Cold Stage Operating temp. (mK)	≤ 50	50	< 50
Cold Stage temp. stability (μK)	1	1	< 1
Cold Stage Cooling power (μW)	2	0.5	> 6
Warmer Stage Stability at Operating Temp. (mK@K)	1@4-6	1@4.5	1@4
Telescope Cooling (power@temp., mW@K)	100@4-6	20@4.5	>20@4 K
Mag. Field at detector assembly (μT)	5	7500	< 5
Allowable vibration levels (milli Newtons, mN)	0.001	5	~ 0
Lifetime (years)	> 5	> 5	> 5

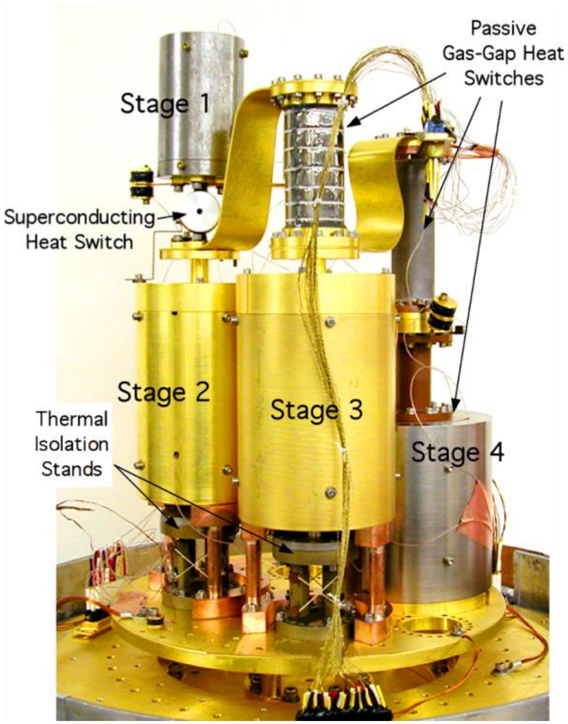
Vibration Reduction

- ADRs have no moving parts; contribute zero vibrations
- Mechanical cryocooler vibrations end up being an issue on flight missions
- Recently Creare demonstrated 10 K operation of their Turbo-Brayton cooler
  - Very high-frequency vibrations - heavily damped by spacecraft structure
- A 10 K superconducting flight-compatible magnet was developed with NASA fundint between 2002 and 2010
  - It’s now possible for a flight CADR to reject heat at 10 K
- These two technologies enable 300 K to 50 mK “vibration-free” cooling

4 - 0.05 K CADR State-of-the-Art

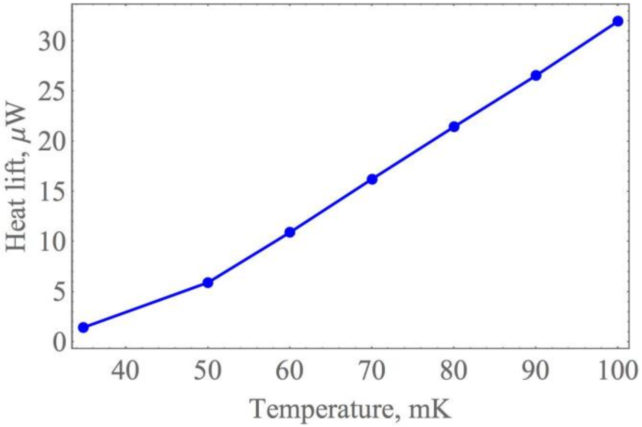
Cryogenics and Fluids Branch

2004 Version



2017 Version
(~35 cm tall)

2004 performance test results



10 - 4 K CADR State-of-the Art

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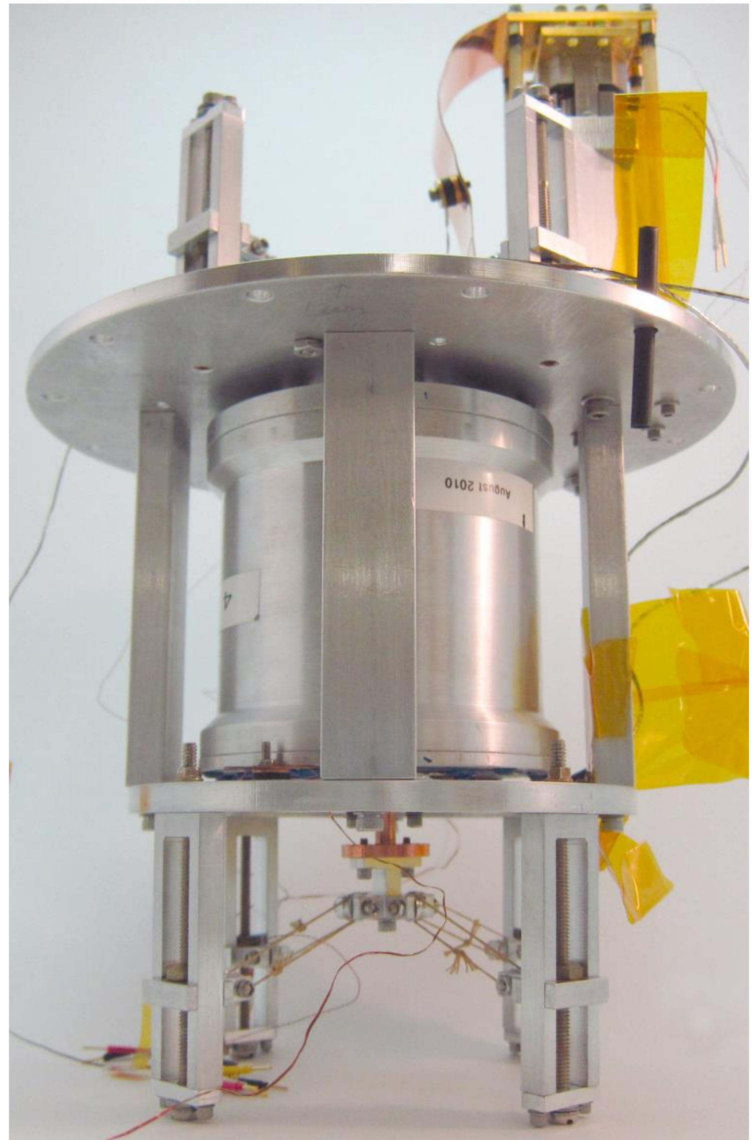
- Proof-of-concept single-stage 10 – 4 K ADR was tested at NASA-GSFC
- Included prototype Nb_3Sn 10 K magnet
- Cooling was demonstrated



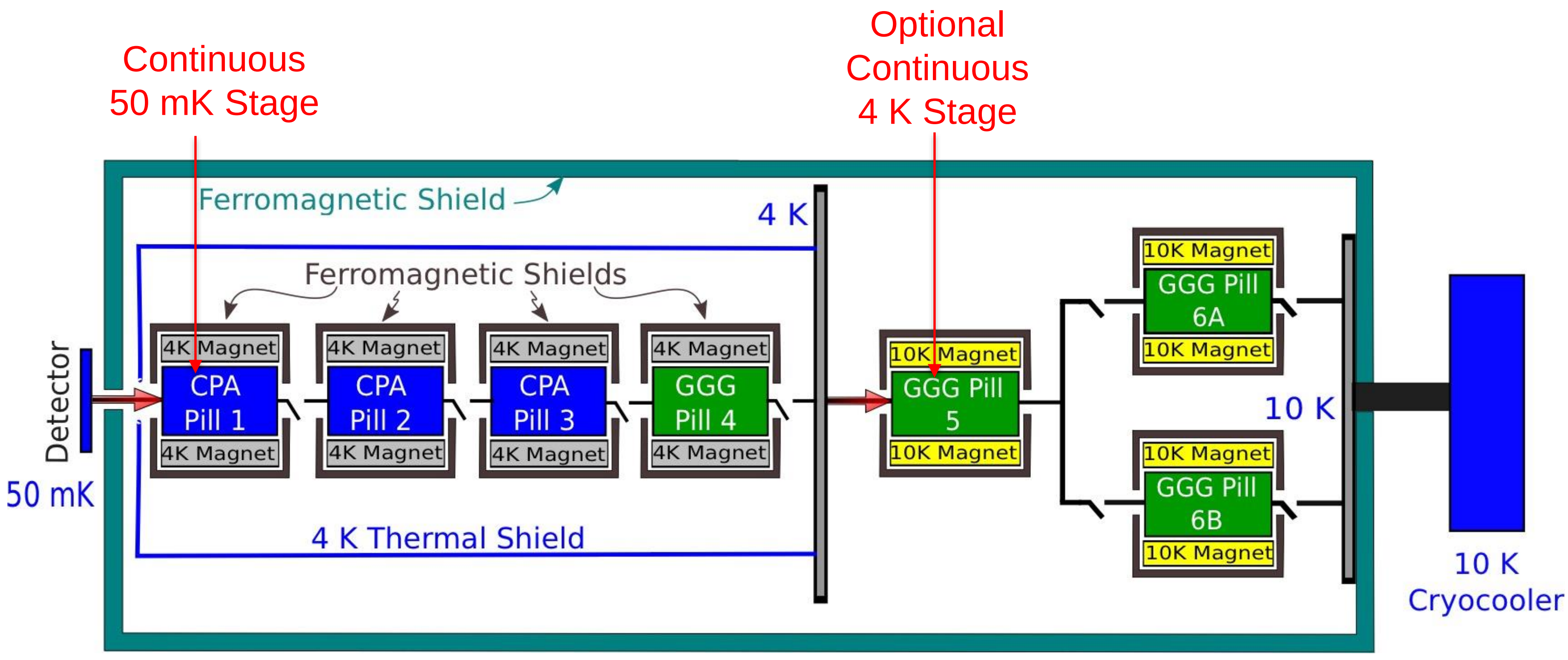
Piezo-electric heat switch

Nb_3SN 10 K magnet

Laboratory Kevlar salt pill suspension

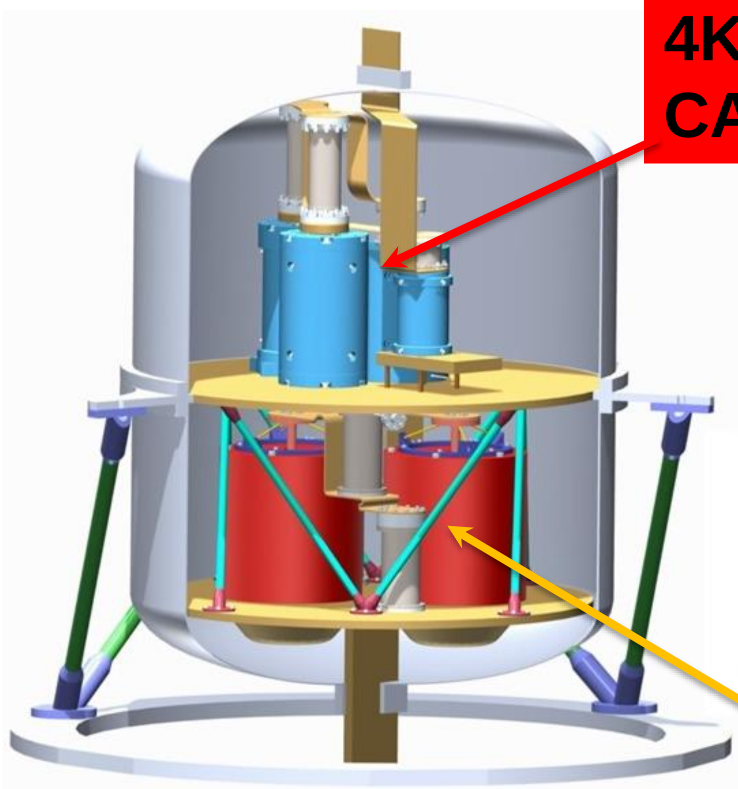
New CADR Schematic

- Stages 1-2 switch is superconducting; all others passive gas-gap
- Includes 10 K vanadium permendur overall shield
- Stage 5 provides extra cooling at 4 K; could be removed to save mass
- 4 K to 50 mK subsystem will be flight-worthy version of lab CADR



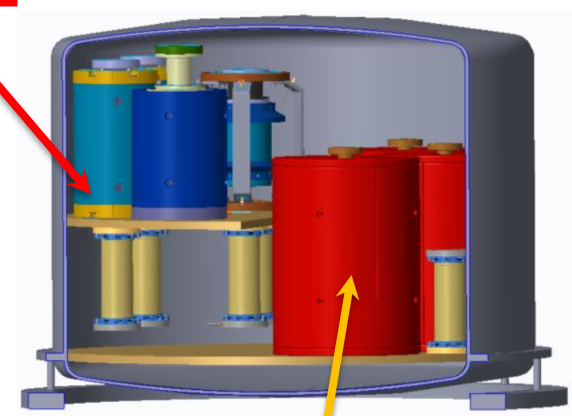
CADR Component Packaging

Original proposed version with 4 K superconducting overall magnetic shield



Re-packaged version with 10 K magnetic shield (4 K thermal shield and some straps not shown)

O.D. ~ 35 cm



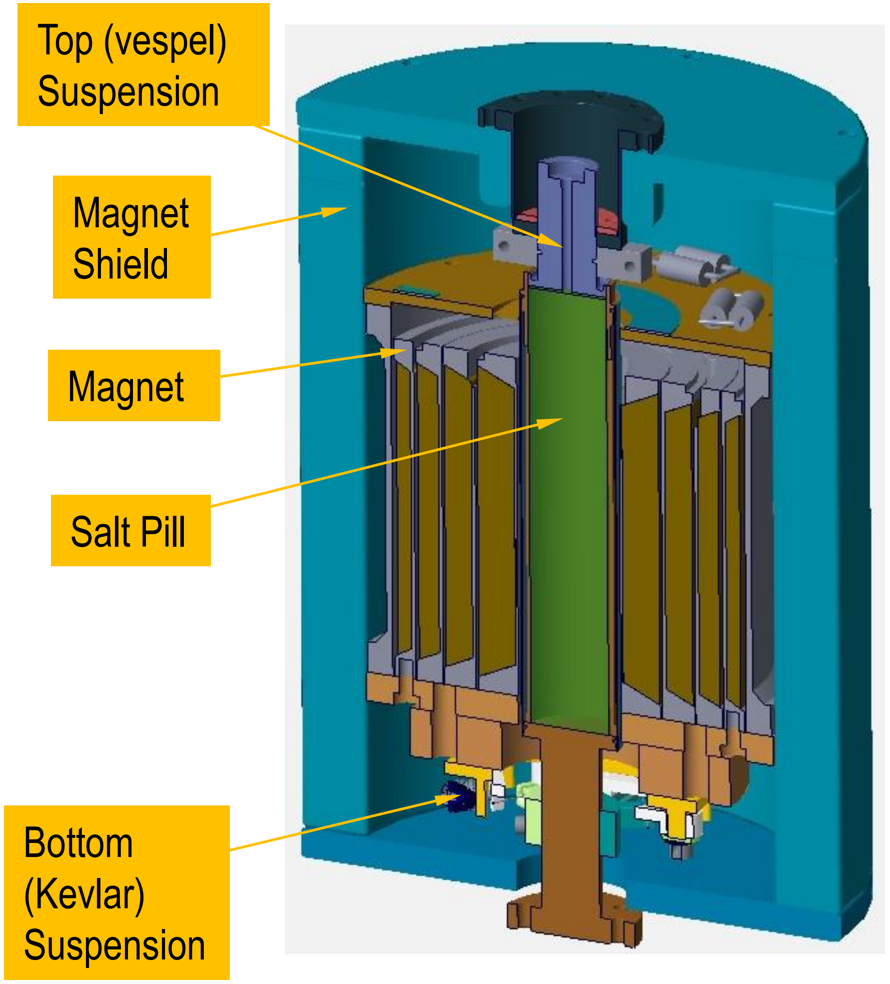
4-stage 4K - 0.05K CADR

2-stage 10K - 4K CADR

3-stage 10K - 4K CADR

Updated 10 - 4 K Stage Design

- Silicon iron magnetic shield
  - minimizes stray field
  - enhances central field
- Magnet hangs from shield
  - 4 concentric coils
  - 4 Tesla max. central field
- GGG pill suspended from shield
  - optimized length: extends beyond magnet coils
  - Kevlar suspension design copied from ASTRO-H



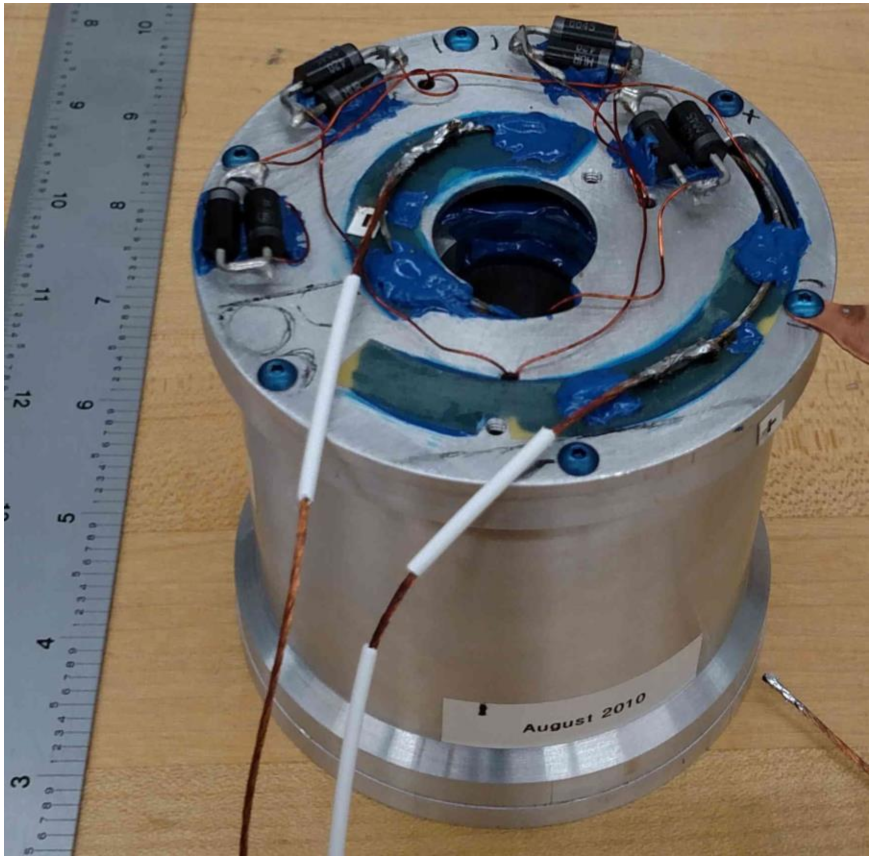
10 K Nb_3Sn Magnet

- Developed from 2002 – 2010 by Superconducting Systems, Inc. with NASA funding

- Central field = 4 Tesla with 6.5 Amp operating current

- Mass = 1.85 kg

- We measured AC heating for one cycle from zero – 4 T– zero field:
  - 0.9 Joules/cycle
  - nearly independent of ramp rate: hysteresis heat dominates
  - for 2 parallel stages with 10 minute overall cycle time: magnet heating = 3 mW at 10 K
  - will re-test soon with shield



10 K Magnet Modeling

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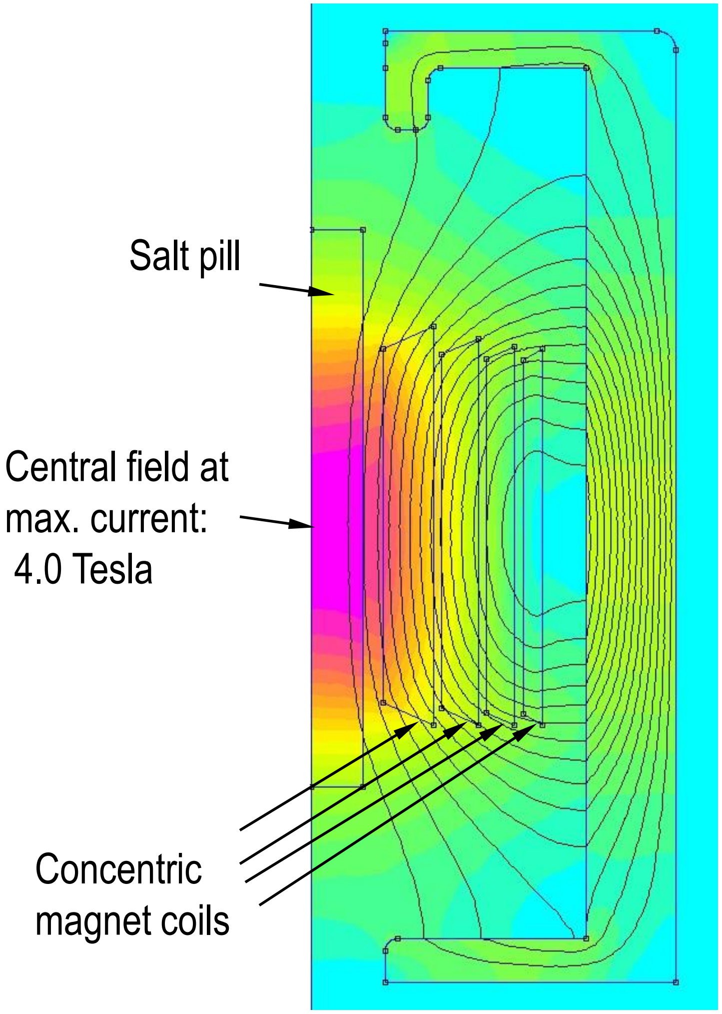
- Structural model showed no resonance modes below 600 Hz

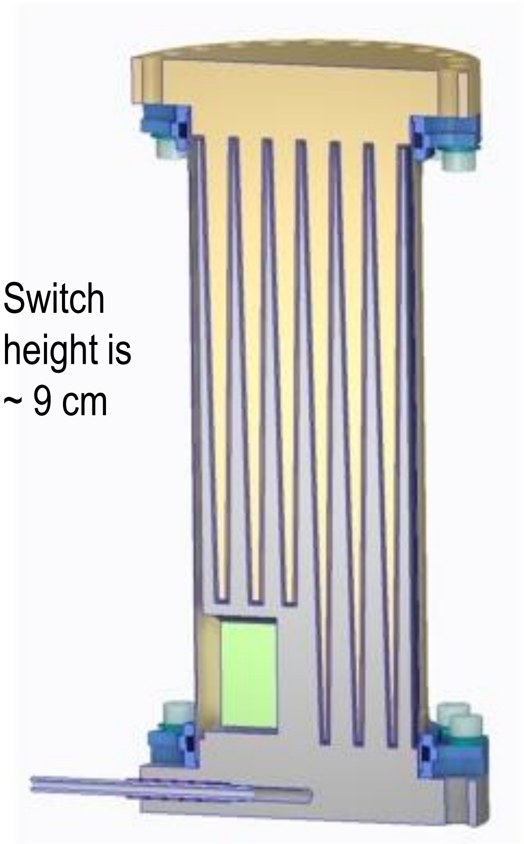
- Magnetic/thermal model results
  - shield's shape and wall thickness chosen to keep its internal field below 2.1 T saturation limit
  - shield enhances central field (or reduces operating current)
  - field as low as 1.5 T produces useful cooling in GGG
  - optimum salt length extends beyond magnet coil ends



10 K – 4 K Gas Gap Heat Switch

- Two copper stages separated by a stainless steel hermetic shell
- ^{3}He gas is sealed inside shell volume
- High gas thermal conduction between interleaved fins when switch is closed
- Contains a charcoal getter on cold side
- Gas pressure optimized so switch opens at just below 10 K
- Test results will be shown in Kimball talk later in this session

Switch height is ~ 9 cm



Plan Forward

- 2017: Demonstrate a one-stage 10 to 4 K ADR
- 2018: Assemble/test a flight-worthy 3-stage (or 2-stage) 10 to 4 K CADR
- 2019:
  - Assemble a flight-worthy 4 to 0.05 K CADR
  - Integrate 10 to 4 K CADR with 4 to 0.05 K CADR
  - Performance test full 10 to 0.05 K CADR
  - Vibrate CADR to flight levels
  - Post-vibe performance test